US009916969B2

(12) **United States Patent**
Jolliffe et al.

(10) **Patent No.: US 9,916,969 B2**
(45) **Date of Patent: Mar. 13, 2018**

(54) **MASS ANALYSER INTERFACE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/740,985**

(22) Filed: **Jan. 14, 2013**

(65) **Prior Publication Data**

US 2014/0197333 A1 Jul. 17, 2014

(51) **Int. Cl.**
H01J 49/04 (2006.01)
H01J 49/06 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 49/044*** (2013.01); ***H01J 49/062*** (2013.01)

(58) **Field of Classification Search**
CPC H01J 49/00; H01J 49/04
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,746,794	A *	5/1988	French	H01J 49/04 250/281
5,338,931	A *	8/1994	Spangler et al.	250/287
5,770,857	A *	6/1998	Fuerstenau	H01J 49/027 250/281
6,630,662	B1 *	10/2003	Loboda	H01J 49/063 250/281
7,932,488	B2	4/2011	Javahery et al.	
2002/0185606	A1 *	12/2002	Smith	G01N 15/1456 250/341.7
2003/0136905	A1 *	7/2003	Franzen et al.	250/292
2004/0079881	A1 *	4/2004	Fischer et al.	250/288
2006/0076484	A1 *	4/2006	Brown et al.	250/290
2009/0212210	A1 *	8/2009	Finlay	H01J 49/0404 250/288
2009/0218484	A1 *	9/2009	Javahery et al.	250/282
2009/0294650	A1 *	12/2009	Schneider	G01N 27/624 250/282
2010/0282961	A1 *	11/2010	Miller et al.	250/282
2011/0095175	A1 *	4/2011	Bateman	G01N 27/624 250/282
2012/0267548	A1 *	10/2012	Vidal-De-Miguel	H01J 49/0422 250/424
2012/0292526	A1 *	11/2012	Hiraoka et al.	250/423 R
2012/0325024	A1 *	12/2012	Vidal-de-Miguel	G01N 27/622 73/863.24

OTHER PUBLICATIONS

Ashcroft et al., "Ionization Methods in Organic Mass Spectrometry", The Royal Society of Chemistry, UK, 1997.*
Kanu et al., "Ion mobility—mass spectrometry," 2008, Journal of Mass Spectrometry, J. Mass Spectrom, vol. 43, pp. 1-22.

* cited by examiner

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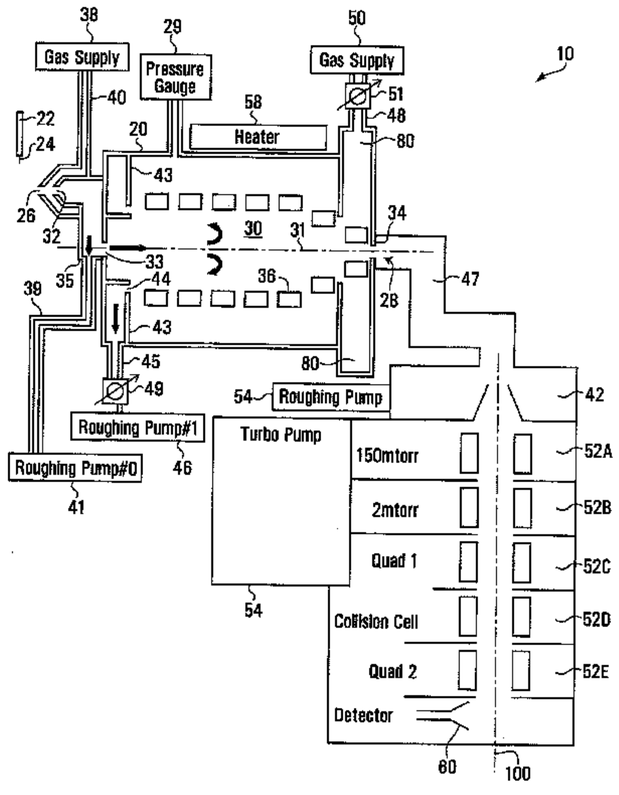
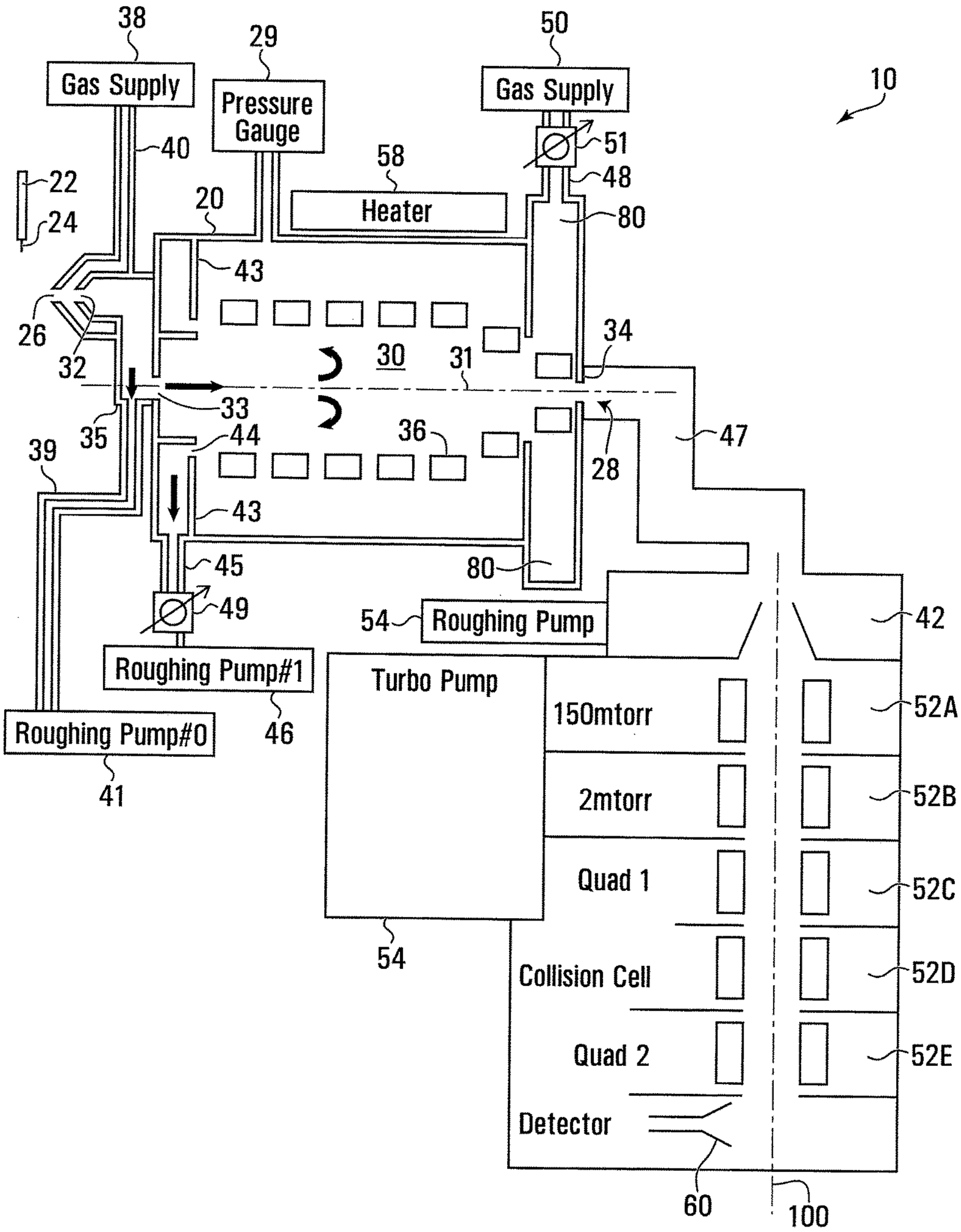
Assistant Examiner — James Choi

(57) **ABSTRACT**

A mass analyzer includes a desolvation chamber into which an upstream gas is injected to provide a counter-flow to said downstream flow in the chamber. The counter-flow may slow the downstream flow of solvated ionized particles in the chamber, while allowing lighter desolvated ions to travel toward an outlet aperture of the desolvation chamber.

32 Claims, 8 Drawing Sheets

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Gas Supply
29
Pressure Gauge
50
Gas Supply
10
40
58
Heater
51
48
22
24
20
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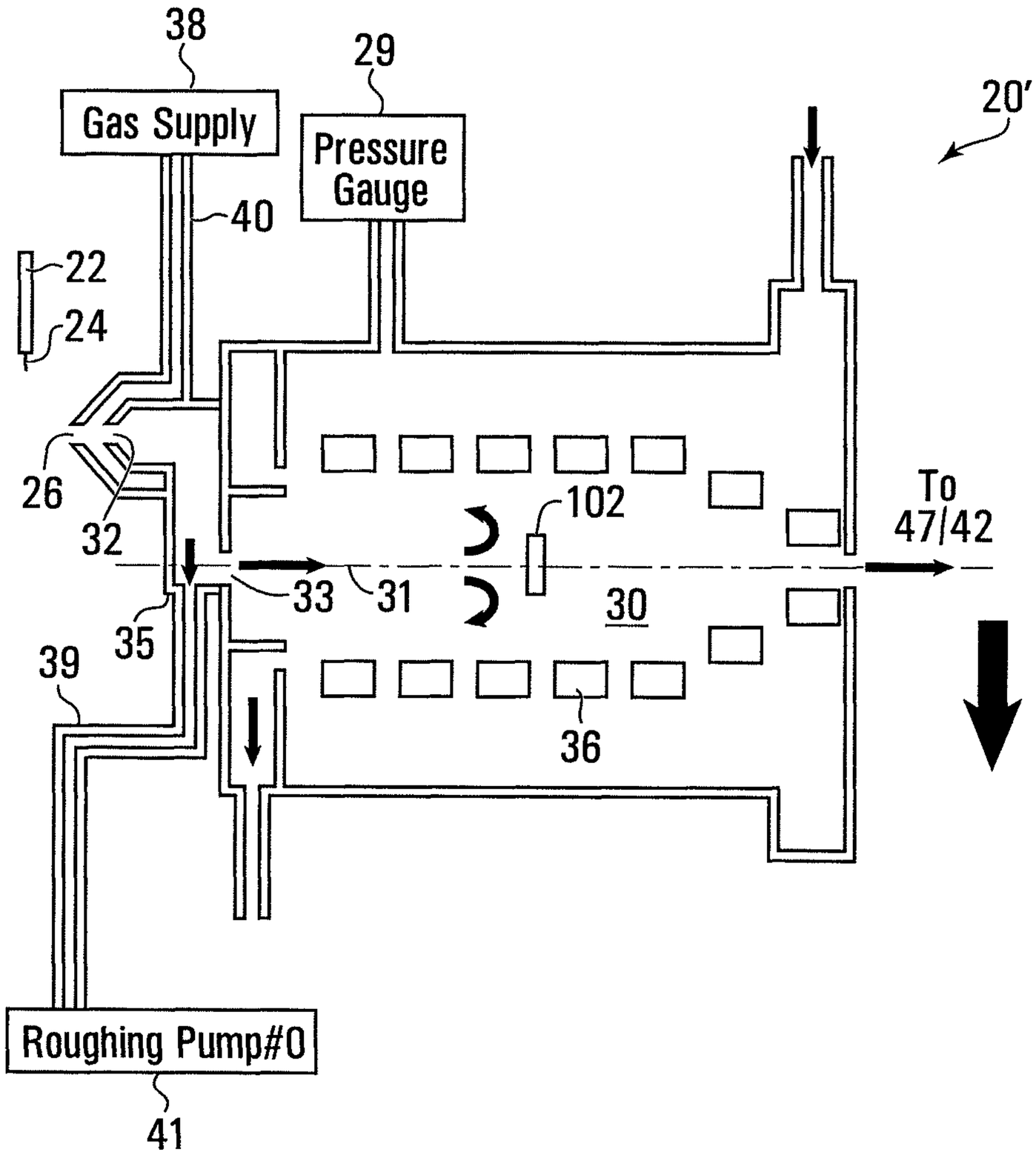
43
26
32
30
31
34
33
35
36
47
39
44
28
43
45
80
49
54
Roughing Pump
42
Roughing Pump#1
Turbo Pump
150mtorr
52A
Roughing Pump#0
46
2mtorr
52B
41
Quad 1
52C
54
Collision Cell
52D
Quad 2
52E
Detector
60
100

FIG. 1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Gas Supply
29
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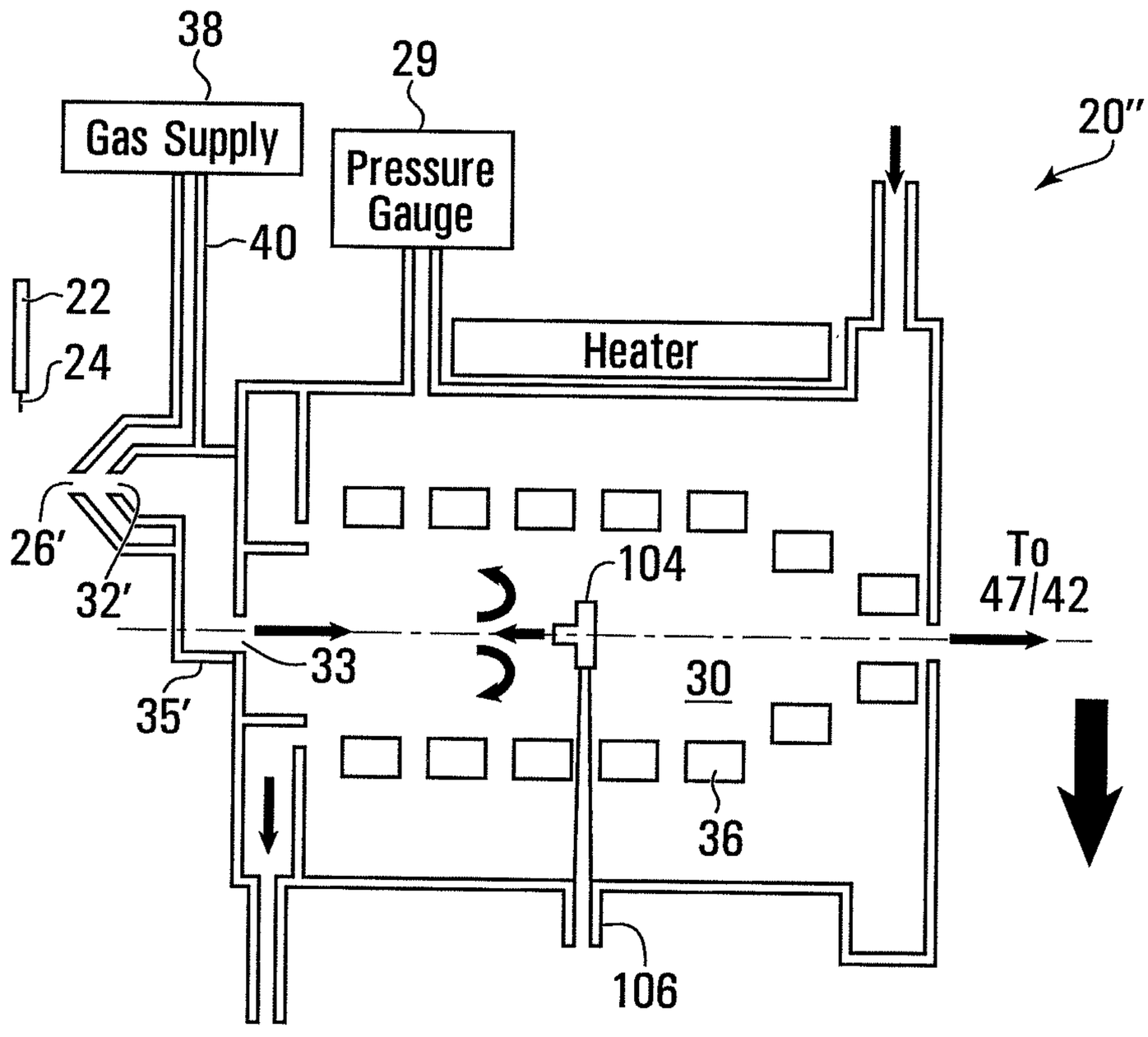
20'
40
22
24
26
32
102
To 47/42
33
31
30
35
39
36
Roughing Pump#0
41

FIG. 2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29
Pressure Gauge
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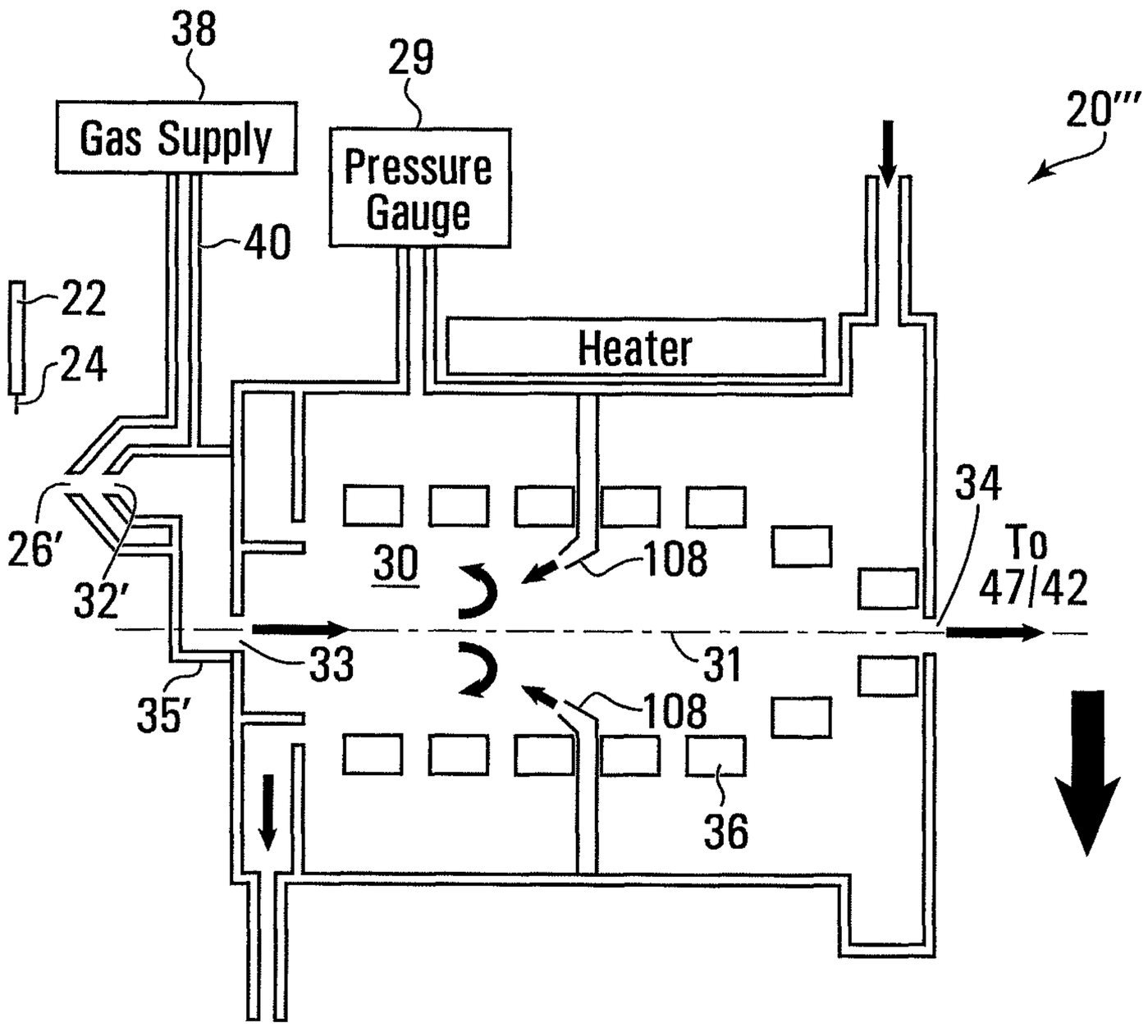
40
22
24
Heater
26'
32'
104
To 47/42
33
30
35'
36
106

FIG. 3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29
Pressure Gauge
20'''
40
22
24
Heater
26'
32'
30
108
34
To 47/42
33
31
35'
108
36

FIG. 4

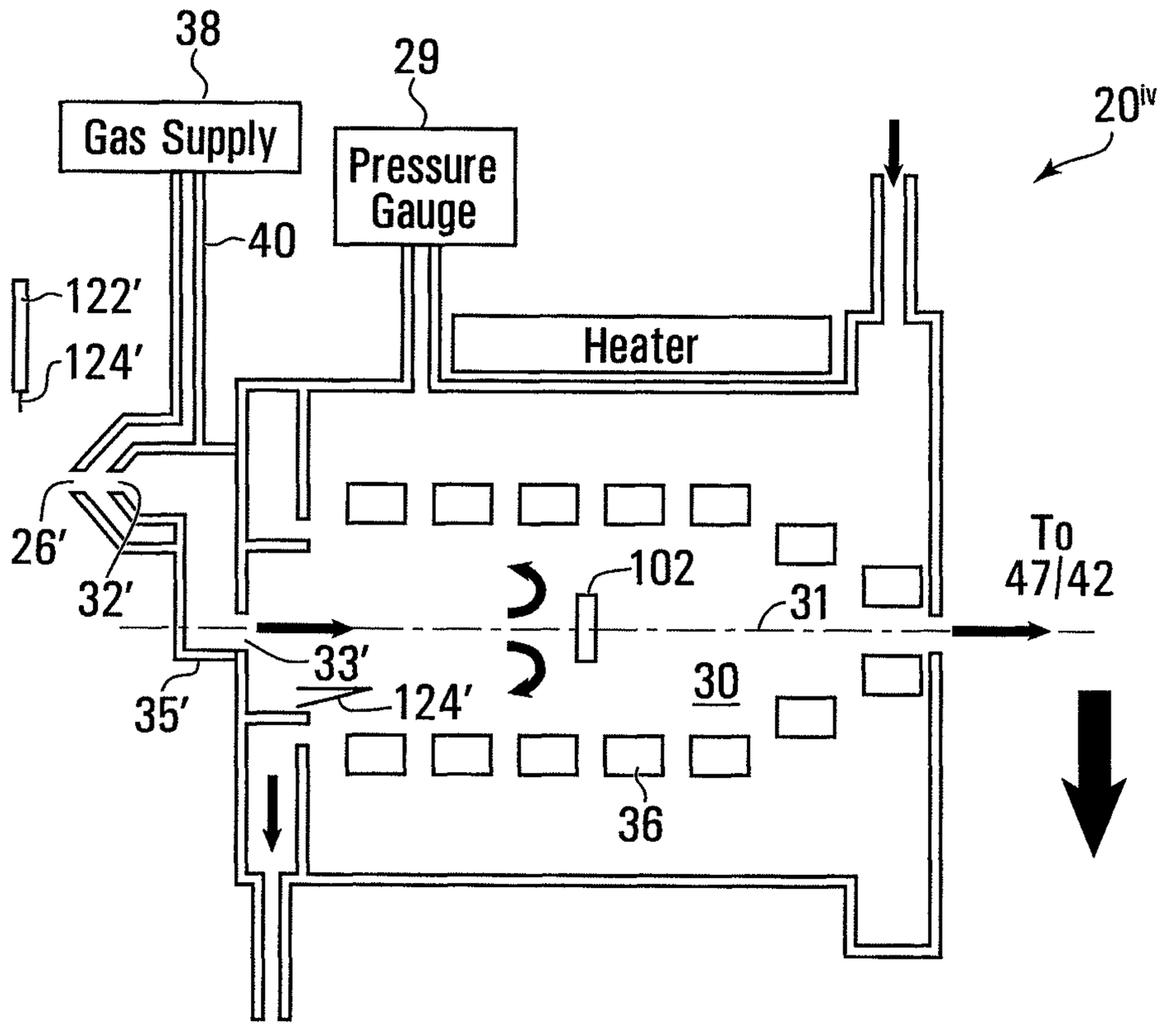

38
29
Gas Supply
Pressure Gauge
20iv
40
122'
124'
Heater
26'
32'
102
31
To 47/42
33'
35'
124'
30
36

FIG. 5

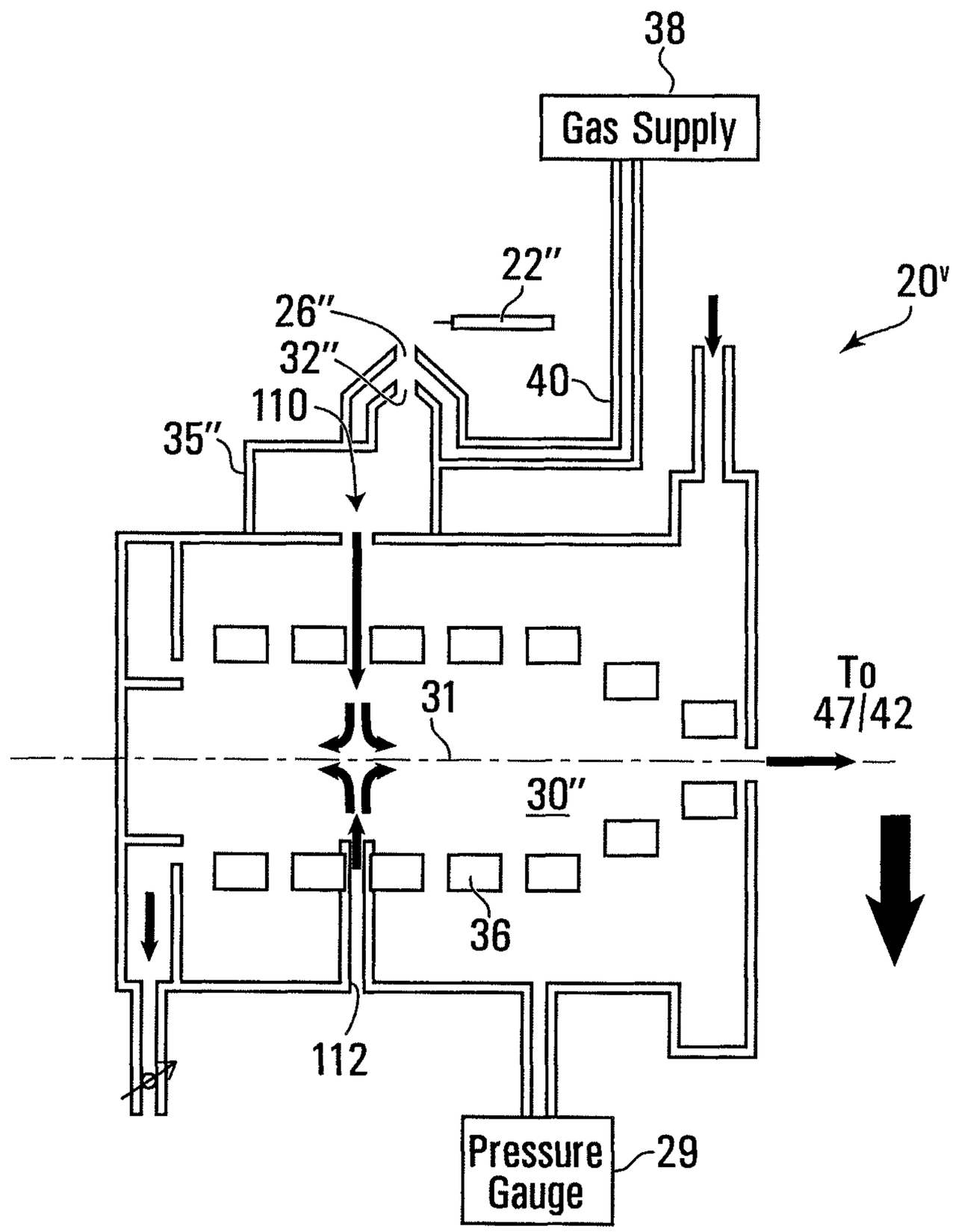

38
Gas Supply
22″
20v
26″
32″
40
110
35″
31
To
47/42
30″
36
112
Pressure
Gauge
29

FIG. 6

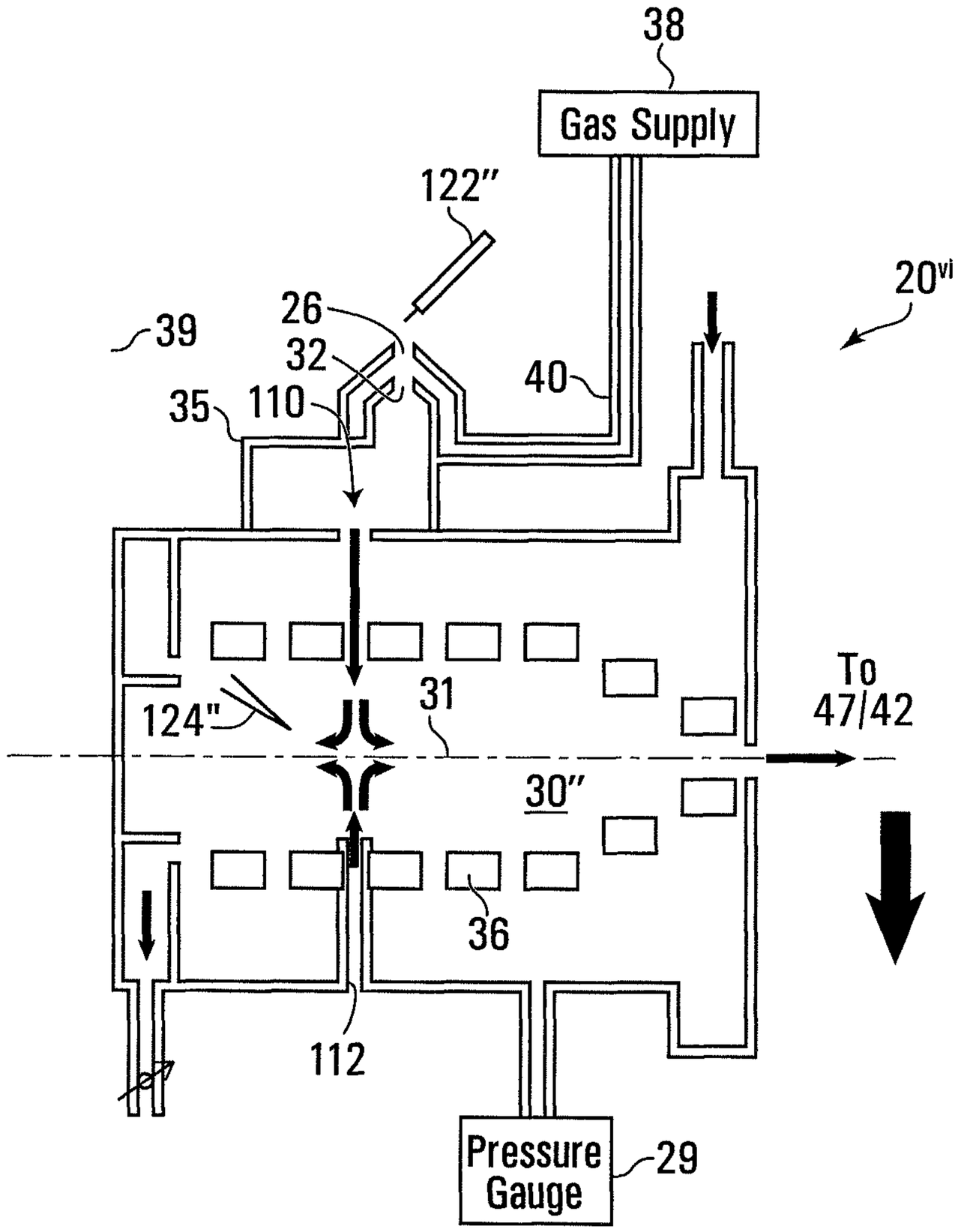
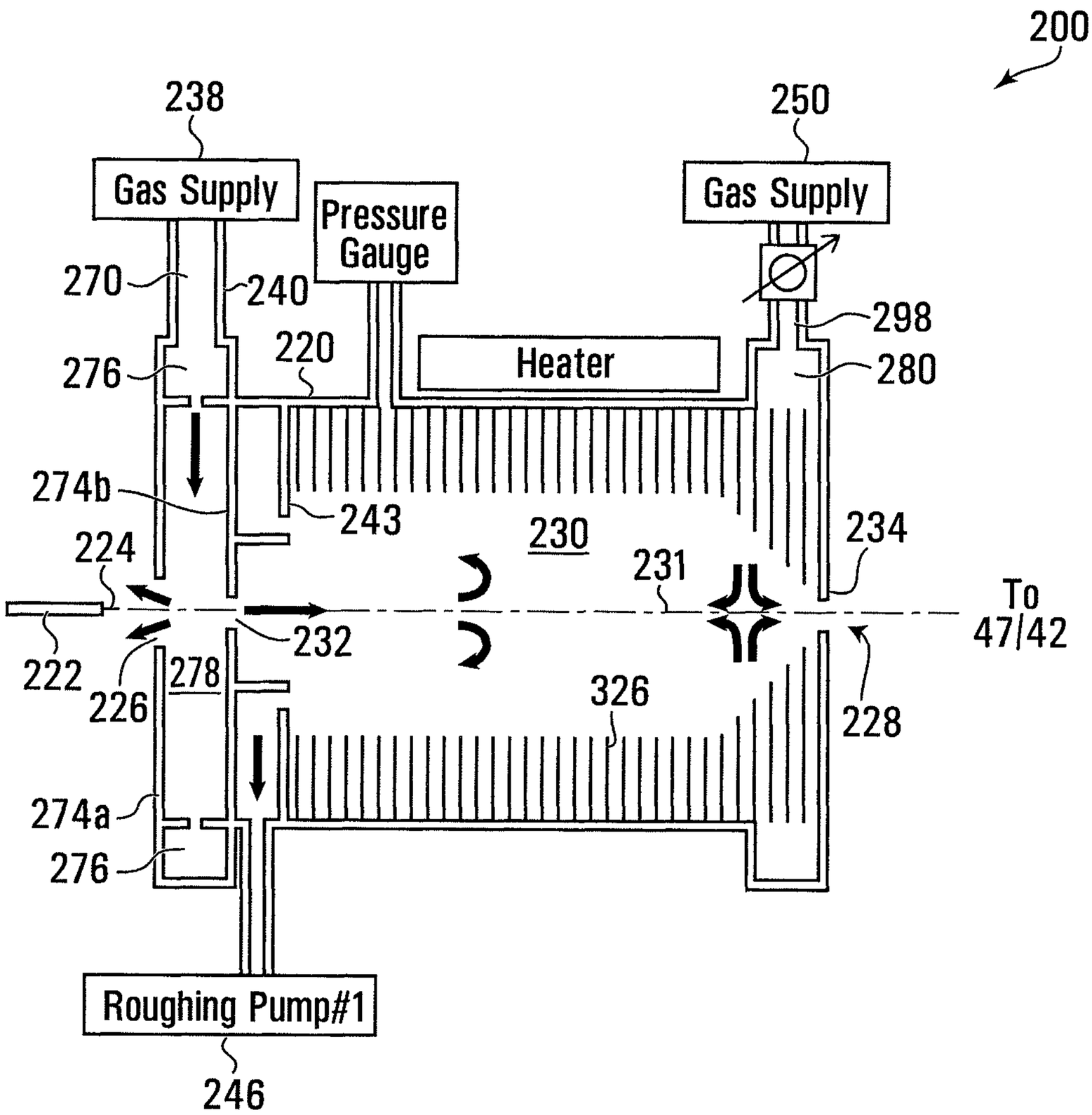

38
Gas Supply
122"
20vi
26
39
32
40
35
110
31
124"
To
47/42
30"
36
112
Pressure
Gauge
29

FIG. 7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238
Gas Supply
Pressure Gauge
250
Gas Supply
270
240
298
220
Heater
276
280
274b
243
230
234
224
231
To 47/42
222
232
278
226
326
228
274a
276
Roughing Pump#1
246

FIG. 8

MASS ANALYSER INTERFACE

FIELD OF THE INVENTION

The present invention relates in general to all analytical instruments and in particular to mass analysers and mass analyser interfaces that include a desolvation chamber(s) that provides a counter flow to aid in desolvation.

BACKGROUND OF THE INVENTION

Mass analysis, and more particularly mass spectrometry, has proven to be an effective analytical technique for identifying unknown compounds and for determining the precise mass of known compounds. Advantageously, compounds can be detected or analysed in minute quantities allowing compounds to be identified at very low concentrations in chemically complex mixtures. Not surprisingly, mass spectrometry has found practical application in medicine, pharmacology, food sciences, semi-conductor manufacturing, environmental sciences, security, and many other fields.

A typical mass spectrometer includes an ion source that ionizes particles of interest. The ions are passed to an analyser region, where they are separated according to their mass (m)-to-charge (z) ratios (m/z). The separated ions are detected at a detector. A signal from the detector may be sent to a computing or similar device where the m/z ratios may be stored together with their relative abundance for presentation in the format of a m/z spectrum.

Typical ion sources are detailed in "Ionization Methods in Organic Mass Spectrometry", Alison E. Ashcroft, The Royal Society of Chemistry, UK, 1997; and the references cited therein. Conventional ion sources may, for example, create ions by electrospray or chemical ionization.

Electrospray ionization involves dispersing liquid containing analyte(s) of interest into a fine aerosol jet of solvated charged droplets. Typically, a nebulizer gas flow is involved in this dispensing process and an impinging heater gas flow assists droplet desolvation. Charged droplets are drawn by an electric field to the sampling inlet of a mass spectrometer. Liquid flows greater than 25 μL/m usually require the various gas flows to be heated for rapid desolvation.

Atmospheric pressure chemical ionization ("APCI") relies on liquid containing analyte of interest to be discharged into a fine aerosol jet of droplets containing the analyte. Again, a nebulizer gas flow is involved and an impinging heater gas flow may assist droplet desolvation. Desolvated analyte molecules are chemically ionized by reagent ions created in close proximity by a corona current.

It has long been recognized that the sampling inlet is a major sensitivity bottleneck: typical diameters of the sampling inlet are about 0.5 mm, and space repulsion of analyte ions acts as a choke upon significant sensitivity increases. Although larger sampling diameters are desired for higher sensitivity, such apertures necessitate larger vacuum pumps. Present vacuum pumping systems are at their practical maximum in terms of size and cost.

Accordingly, alternative approaches are required.

SUMMARY OF THE INVENTION

Exemplary of an embodiment of the present invention, a mass analyzer includes a desolvation chamber into which an upstream gas is injected to provide a counter-flow to the downstream flow in the chamber. The counter flow may slow the downstream flow of solvated ionized particles in the chamber, while allowing lighter desolvated ions to travel toward an outlet aperture of the chamber. The chamber may be heated to aid in desolvation. Further, the chamber may be maintained at a low (below atmosphere) pressure.

In an embodiment, a mass analyser interface, includes a desolvation chamber having an inlet for receiving solvated analyte particles from a source of analyte particles, and an outlet aperture. An electric field source provides an electric field to urge ionized particles within the chamber from the inlet toward the outlet aperture, creating a downstream flow of ionized particles. A gas injection port injects an upstream gas proximate the outlet aperture, to provide a counter-flow to the downstream flow at the aperture, to slow the downstream flow as the ionized particles travel toward the outlet aperture. At least one evacuation port allows injected gas to escape from the desolvation chamber.

In another embodiment, a method of providing desolvated ions in a mass analyzer includes: providing solvated analyte particles from a source of analyte particles into a desolvation chamber having an inlet and an outlet aperture; providing an electric field to urge ionized particles toward the outlet aperture in a downstream flow; heating the desolvation chamber; and injecting an upstream gas proximate the outlet aperture, to provide a counter-flow to the downstream flow at the aperture, to slow the downstream flow and any solvated particles entrained therein.

Other aspects and features of the present invention will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In the figures which illustrate by way of example only, embodiments of the present invention,

FIG. **1** is a schematic block diagram of a mass analyser, including a mass analyser interface, exemplary of an embodiment of the present invention.

FIGS. **2-8** are schematic block diagrams of further mass analyser interfaces, exemplary of embodiments of the present invention.

DETAILED DESCRIPTION

FIG. **1** illustrates a mass analyser **10**, including a mass analyser interface **20**, exemplary of an embodiment of the present invention.

Mass analyser interface **20** guides analyte particles from a source **22** of analyte particles. In the analyser **10**, the analyte source provides ionized solvated analyte, and may for example take the form of an electrospray (ES) emitter **24** at a pressure of about one atmosphere (1 atm=760 torr). Interface **20** guides the solvated analyte from an inlet/exit opening **26** to a pressure less than about 4 torr, to produce desolvated ionized analyte at an outlet **28**, and ultimately to the remainder of mass analyser **10**.

Mass analyser **10** further includes conventional downstream mass analysis stages, including for example guide stages **52***a*-**52***e* to guide ionized particles along a guide axis **100**. Stages **52***a*-**52***e* may include mass quadrupole filter stages **52***c* and **52***e*, and collision cell **52***d*, all leading ionized particles to a detector **66**. One or more pump(s) **54** gradually reduce the pressure from stage to stage within stages **52***a*-**52***e*.

Mass analyser interface **20** includes a desolvation chamber **30** having an inlet aperture **33** defining inlet for receiving

solvated analyte particles and providing an outlet aperture **34** defining outlet **28** to a second chamber **42**. A low pressure interface **35** receives solvated ions fed to inlet aperture **33** at opening **26** of sampling inlet **32**, for example from ES emitter **24** that ionizes the solvated analyte particles. An example low pressure interface **35** is, for example, disclosed in U.S. Pat. No. 7,405,398, the contents of which are hereby incorporated by reference. Downstream chamber **42** may be in communication with desolvation chamber **30** directly, or indirectly, for example, by way of conduit **47**.

A DC voltage source (not shown) maintains a potential difference between source **22** and sampling inlet **32** to attract ions from source **22** to sampling inlet **32** of interface **35**. Analyte source **22** is typically at about atmospheric pressure (e.g. 760 torr). In alternate embodiments, pressure at source **22** could range from 1 atm to 10 atm or higher. Similarly, source **22** is depicted as a single ES emitter **24**, but alternatives are possible. For example, an array of ES emitters each associated with its own separate inlet aperture (like sampling inlet **32**) is possible. Likewise, although ES emitter **24** is oriented at 90° to a central axis **31** of chamber **30**, it could similarly be oriented at another angle (e.g. parallel or otherwise) to this axis. Further, as will become apparent, in other embodiments provided solvated analyte need not be ionized prior to entering interface **35** or chamber **30**, but may instead be ionized within interface **35** or chamber **30**.

As disclosed in U.S. Pat. No. 7,405,398, interface **35** may entrain analyte in a gas, and provide a tortuous path between sampling inlet **32** and aperture **33**, to assist in the liberation of analyte ions therein. Further, the outlet of interface **35** may provide a substantially laminar flow of gas and entrained analyte particles. Optionally, interface **35** may include a heater (not shown) and/or one or more ionizers for heating gas and analyte, and ionizing analyte in interface **35**.

In the depicted embodiment, interface **35** is a split-flow interface with gas provided by a supply **38** leaving interface **35** through inlet/exit opening **26** and conduit **39** to roughing pump **41**. As will become apparent, interface **35** may be replaced with a direct flow interface, in which substantially all gas entering the interface will exit into chamber **30**. As well, inlet/exit opening **26** is aligned with sampling inlet **32**, but need not be so located. Opening **26** is spaced from sampling inlet **32** by about 3 mm.

Desolvation chamber **30** may be formed from a generally cylindrical casing, extending along an axis **31**. The casing has inlet aperture **33** at one end and outlet aperture **34** at the second opposing end, formed therein. An annular shroud **43** encircles inlet aperture **33**, interior to chamber **30**. Other geometries are of course possible.

Chamber **30** is typically formed from a heat conductive material, such as metal, and may optionally be heated, by a heater **58**. Heater **58** may be configured to heat the inner cylindrical wall of chamber **30** to more than 100 C (e.g. 300 C or higher). Sampling inlet and outlet aperture **32** and **34** may be circular, or any other suitable shape. Inlet aperture **32** may alternatively, or additionally, take the form of a cylindrical or conical tube (not shown) or flat plate that may optionally be heated.

Gas flow within chamber **30** is influenced principally by the flow through sampling inlet **32** and outlet aperture **34**, and the introduction of gases through ports **40** and **48**, and the evacuation of gases through evacuation port **44**, as detailed below. Flow through sampling inlet **32** is largely independent of the flow from port **40** to conduit **39**, as this flow is set to be so low—and the opening **26** is large—that the pressure upstream of sampling inlet **32** is constant at about atmosphere (1 atm).

The pressure within chamber **30** may be measured by a pressure gauge **29**, in flow communication with the interior chamber **30**. The flow of gases through ports **44** and **48** may be electronically controlled, for example using feedback control, as described below.

Gas introduced proximate sampling inlet **32** through port **40** may be introduced into chamber **30** by way of interface **35**, effectively positioned upstream of inlet aperture **33**.

Gas injection port **48** injects a drying gas from a gas source **50**, by way of a gas flow controller **51**, into chamber **30** proximate outlet aperture **34**, and is located on the cylindrical wall of chamber **30**, axially proximate outlet aperture **34**. Typical gas types from source **50** are again air or nitrogen—clean and dry. An annular manifold **80**, located exterior to chamber **30** may ensure gas entering through port **48** enters chamber **30** uniformly around axis **31**, with a flow generally toward axis **31**. Manifold **80** may have evenly spaced openings on its inner wall to ensure even distribution of gas from flow controller **51**. An inline heater (not shown) may additionally heat gas from gas source **50**, prior to the gas entering chamber **30**.

In general, forces on desolvated ions and charged droplets are different in a viscous flow and in an electric field. For the same flow and electric field, droplets experience the force of viscous flow more than that of electric fields, and vice-versa for desolvated ions. As such, gas injected through gas injection port **48** provides a counter flow that maintains droplets within chamber **30**, while allowing desolvated ions to travel to outlet aperture **34** and thus aids in desolvation. The average axial electric field and counter flow in chamber **30** may be adjusted to enable desolvated ions to travel to outlet aperture **34** in chamber **30**, but prevent droplets from so travelling.

The length of the desolvation chamber may thus be chosen to be inversely proportional to ion transit time and can be selected to allow a sufficient number of energy transferring collisions for effective desolvation, for a given temperature, pressure and counter flow. The pressure and temperature can be selected to produce a number density and heat effect sufficient for desolvation while also optimizing the effect of DC and RF confining electric fields.

In an embodiment, desolvation chamber **30** may be about 20 cm in length and 8 cm in diameter, with sampling inlet **32** of interface **35** having a diameter of about 0.5 mm. The typical diameter of inlet aperture **33** may range from about 4 mm to 8 mm, providing minimal flow impedance between sampling inlet **32** and inlet aperture **33**. Depending on the desired gas flow through outlet aperture **34**, the diameter of outlet aperture **34** can typically range from 1 mm to 5 mm.

Evacuation port **44** for chamber **30** is shown terminating in an annular port extending through an outer cylindrical wall of chamber **30**, in close axial proximity to inlet aperture **33**. Evacuation port **44**, may extend from, or be part of an evacuation conduit **45** that extends from the interior of chamber **30**, proximate its central axis to roughing pump **46**. Evacuation port **44** (like typical roughing pump ports) may be a series of apertures, but in general, may be reasonably symmetric about and proximate the central axis of chamber **30**. In this way, the flow via port **44** from chamber **30** will be flowing roughly parallel to the central axis **31** of chamber **30**.

Roughing pump **46** evacuates gases from chamber **30** through evacuation port **44**, and thereby regulates the pressure in chamber **30**. Roughing pump **46** may be adjustable, so that its flow rate may be adjusted and electronically controlled. Roughing pump **46** may, for example, be a variable frequency pump.

Optionally an adjustable flow restrictor **49** with pressure sensors immediate upstream and downstream of it, may be placed in conduit **45** between roughing pump **46** and chamber **30** to maintain a desired dry gas flow in chamber **30**. Again, flow restrictor **49** could be electronically controlled.

Annular wall **43** on the interior of chamber **30** further shape the direction of flow of gases leaving chamber **30** through port **44**.

A multi-polar (e.g. quadrupolar, hexapolar, octopolar, etc) multi-stage RF ion guide **36** is disposed in desolvation chamber **30**. RF ion guides are known to those of ordinary skill. A possible ion guide **36** is for example disclosed in U.S. Pat. No. 7,932,488, the contents of which are hereby incorporated by reference. Ion guide **36** will typically be low capacitance in order to allow application of a voltage from a voltage source (not shown) at high RF frequencies and voltages, e.g., 2 MHz at 1 kV_{pp}. In addition, ion guide **36** will typically create a large average axial electric field: for example, in FIG. **1**, a 5 kV electrostatic drop from one end of ion guide **36** of length 10 cm and constant interior diameter and equally spaced stages, may produce a 500 V/cm field. Different geometries and voltages on ion guide **36** could be used to achieve a different field pattern. For example, a cone section of ion guide **36** could generate a hemispherical electric field that has an electric field strength that rises rapidly and focuses ions toward outlet aperture **34** as ions proceed along the cone section of ion guide **36**. Average electric fields in excess of 5000 V/cm may thus be possible. Alternatively, a voltage pulsed ion guide may be employed, to generate electrodynamic fields, having similar average axial fields. FIG. **1** illustrates an example shape for ion guide **36**. Other shapes are of course possible, an ion guide cone with an inner angle usually ranging from 5° to more than 90° is possible; or a non-conical design may be possible. In addition, ion guide **36** shown in FIG. **1**, could be configured to as a ring ion guide, as known to those of ordinary skill. As well, the axial field could be produced otherwise without use of an ion guide or ring ion guide.

A second chamber **42** is in flow communication with the desolvation chamber **30**, by way of outlet aperture **34** connecting the desolvation chamber **30** to the second chamber **42**. Chamber **42** is shown to principally transport analyte, but chamber **42** could further provide ion mobility selection, as for example discussed in "Ion Mobility-Mass Spectrometry", JOURNAL OF MASS SPECTROMETRY, J. Mass Spectrom. 2008; 43: 1-22.

A conduit **47** connects outlet aperture **34** to the second chamber **42** and the remainder of mass analyser **10**. Example conduit **47** introduces several 90° bends into the flow of analyte, however, the central axis of chamber **30** could be located co-axial with guide axis **100**. Of note, the axis of downstream gas flow from inlet aperture **33** to outlet aperture **34** of desolvation chamber **30** is different than the guide axis **100** through guide stages **52**. Conduit **47** could, however, be straight or eliminated entirely The mass analyser downstream of desolvation chamber **30** need not be quadrupole based as shown, but may include any mass selective device.

In operation, pressure within chamber **30** may be maintained below 1 atm—for example at about 76 torr (or 1/10 atm), but could easily be chosen to range from 1/100 atm to 1 atm. To maintain a fixed pressure in chamber **30** as measured by pressure gauge **29** while accommodating different dry gas flows from flow controller **51**, the flow rate of roughing pump **46** may be adjusted, by way of a controller or otherwise.

As noted, the pressure at source **22** is typically at about atmosphere. Analyte particles are solvated at ES emitter **24**. Solvated ions and charged liquid droplets from source **22** are drawn to sampling inlet **32** by electric fields. The flow through sampling inlet **32** further transports the mixture through inlet aperture **33**. Ion guide **36** contains the ionized particles proximate axis **31**, and provides an axial electric field to urge ions from inlet aperture **33** to outlet aperture **34** generally along axis **31**.

The axial electric field extends throughout the length of chamber **30**, to urge charged particles from inlet aperture **33** to outlet aperture **34**.

Gas flow introduced from gas source **38** through interface **35** splits into two flow portions: one portion flows through opening **26**—acting as an exit—opposing the flow of charged droplets from source **22**/ES emitter **24**, while the other portion flows through sampling inlet **32** due to the pressure difference between the region of source **22** and chamber **30**—with the pressure at sampling inlet **32** and inlet aperture **33** being marginally above the pressure in chamber **30**. The portion that flows through sampling inlet **32** and ultimately into chamber **30** entrains charged droplets and transports them through inlet aperture **33** and toward outlet aperture **34**.

The temperature of the gas flow from source **38** and the temperature of the analyte path defined by interface **35** assist in determining the degree of ES droplet desolvation through inlet aperture **33**. Typical gas type from source **38** is clean and dry air or nitrogen. The gas pressure from gas source **38** may be adjusted to provide sufficient flow.

As shown approximately by the solid arrows, the flow of charged droplets through aperture **33** slows, expands, reverses direction, and folds back toward aperture(s) **44** leading to roughing pump **46**. This pumping design is intended to slow the velocity of droplets from source **22**, allowing the droplet time to absorb heat from the surrounding hot gas, as well as absorbing the black body radiation from the heated walls of chamber **30**, resulting in desolvated ions.

Adjustable flow restrictor **49** can also be adjusted to ensure a reasonably constant gas flux through roughing pump **46**, thereby adjusting residence time of entrained droplets within chamber **30**. Without roughing pump **46**—or other pumping system—all gas entering chamber **30** through inlet aperture **33** will exit through outlet aperture **34**. If this gas containing droplets with or without high salt and protein content (and the like) enters outlet aperture **34**, the droplets alone can cause electrical discharge in chamber **42**, or conduit **47** leading thereto (or subsequent lower pressure regions—e.g.), and the salt and protein can be deposited on downstream components of mass analyser **10**, causing sensitivity degradation.

Proximate outlet **34**, gas flow into chamber **30** through gas injection port **48** from gas source **50** splits into two flows: one portion—a counter flow that flows away from outlet aperture **34** opposing the flow of charged droplets emanating from inlet aperture **33**—and another portion that flows in the direction of outlet aperture **34**, caused by the pressure difference between chamber **30** and conduit **47**. The counter flow further slows and desolvates the downstream flow of solvated ionized particles entrained therein, as the solvated ionized particles travel through the desolvation chamber **30** from inlet aperture **33** toward outlet aperture **34**.

The flow toward outlet aperture **34** entrains now desolvated ions and transports them through outlet aperture **34** into conduit **47** and onto chamber **42**. The temperature of the counter gas flow from source **50** greatly determines the

degree of ES droplet desolvation. For example, a temperature of 200° C. or higher may be used.

In typical operation, gas flows through sampling inlet **32** from atmosphere through aperture **33** into chamber **30** at about 0.1 atm, and subsequently through aperture **34** into a conduit **47** at roughly 0.01 atm. With no drying gas flow from gas flow controller **51** and no flow through aperture **44**, a typical inlet aperture of 0.5 mm diameter requires an outlet aperture **34** diameter of 1.6 mm, i.e., the gas flux of about 36 atm-cc/s flows through both apertures. Adding drying gas flow from flow controller **51** will increase the pressure in chamber **30** from 0.1 atm, and therefore the pumping speed through aperture **44** can be increased—usually by increasing the frequency of the roughing pump **46**—to maintain the pressure in chamber **30** at 0.1 atm.

Conveniently, outlet aperture **34** feeding the remainder of mass spectrometer **10** is larger than a typical inlet aperture at or above atmospheric pressure found in conventional mass spectrometers. That is, in conventional mass spectrometers, desolvated ions are provided through an aperture at atmospheric pressure through a sampling orifice. The typical sampling orifice is, for example, about 0.5 mm in diameter.

In interface **20**, solvated ions enter desolvation chamber **30** and desolvate therein. Droplets remain, on average, resident in chamber for a longer time due to the counter flow introduced through gas injection port **48**. Desolvated ions then exit at lower pressure (e.g. at ⅒th atmospheric pressure) through a outlet orifice **34** having a 1.6 mm diameter. Provided the desolvated ion densities are reasonably similar to those of a conventional mass spectrometer, and are extracted at a similar velocity, the ion flux through outlet aperture **34** in interface **20** will be correspondingly larger than the usual ion flux through a conventional sampling orifice. For example, if the area of outlet aperture **34** is ten times larger than a conventional sampling orifice, the ion flow will increase by a factor of ten, as will the sensitivity.

Although inlet aperture **33** is shown on axis **31** of chamber **30**, it could be located off-axis. In addition, although the direction of flow through sampling inlet **32** is shown as parallel axis **31**, alternatives are also possible. Although not shown, reactive gases may also be introduced into chamber **30** are also possible for ion-gas reaction manipulation. Likewise, although source **22** has been described as an ES emitter, ions drawn toward sampling inlet **32** need not originate from an ES emitter: any approximately atmospheric ion source that produces ions will suffice.

In an alternate embodiment illustrated in FIG. **2**, a mass analyser interface **20'** is depicted. Mass analyser interface **20'** is generally the same as mass analyser interface **20** (FIG. **1**) but also includes a jet disrupter **102**, located on the interior of chamber **30**, proximate its center. Jet disrupter **102** may be used to further desolvate the largest droplets in the droplet mixture entering through sampling inlet **32**. Typical jet disruptors **102** disturb the incoming jet flow by their physical presence and an applied voltage. An example jet disruptor **102** may, for example, take the form of a 1 mm thick, 5 mm cylindrical disc, or a 5 mm sphere. Example jet disruptors are detailed in U.S. Pat. No. 7,671,344.

In another alternate embodiment illustrated in FIG. **3**, a mass analyser interface **20"** is depicted. Mass analyser interface **20"** is generally the same as mass analyser interface **20'** (FIG. **2**), except that the jet disrupter **104** provides a gas flow component opposing the flow through inlet sampling inlet **32'**, along axis **31**, and that interface **35'** is unlike interface **35**, in that interface **35'** is not a split flow interface, but instead is a direct flow interface. Gas provided by gas supply **38** primarily exits interface **35'** into desolvation chamber **30** through inlet aperture **33'**. In this case, jet disruptor **104** can affect the incoming jet(s) from sampling inlet **32'** by gas flow from another source, provided to jet disruptor **104** as well as its physical and electrical characteristics. As required, a conduit **106** in flow communication with jet disruptor **104** may extend from the exterior of chamber **30'** to a gas source (now shown). The gas pressure from the disruptor **104** is relative to the pressure in chamber **30**, sufficient to create the counter flow. For example, flow through disruptor **104** may be about one half the flow through sampling inlet **32'**.

In a further alternate embodiment illustrated in FIG. **4**, a mass analyser interface **20"'** is depicted. Mass analyser interface **20"'** is generally the same as mass analyser interface **20"** (FIG. **3**), except that two gas jet disrupters **108** are used. In this embodiment, the two gas jet disrupters **108** are on either side of the central axis **31** of chamber **30**. The gas flow from these two gas jet disruptors **108** performs the principal function of jet disruption from sampling inlet **32'**. Again, a gas source (not shown) may feed jet disruptors **108**. Although two gas jet disruptors are shown at 180°, a multiplicity of such disruptors, such as four equally spaced at 90° are possible. Jet disruptors **108** may be located at chosen locations within chamber **30**, and may be located in/along the flow from sampling inlet **32'** to outlet aperture **34**, for example along axis **31**. Some may likewise be located off axis, away from the downstream flow and central axis **31**.

In an alternate embodiment illustrated in FIG. **5**, a mass analyser interface $\mathbf{20}^{(iv)}$ is similar to mass analyser **20"'** of FIG. **4** except that ES emitter **24** has been replaced with a sprayer **122'**. Sprayer **122'** volatilizes liquid analyte at atmospheric pressure by, for example by mixing heated, eluted analyte at relatively high temperatures (e.g. above 400 degrees Celsius) with a high flow rate nebulising gas. Some or all of this aerosol cloud is introduced into chamber **30**, at sub-atmospheric pressure. In chamber **30**, the aerosol is subjected to a corona discharge by corona emitter **124'**, as shown. Example sprayers and corona emitter are thus similar to those used in APCI interfaces, but separated from another and operating in different pressure regimes, as will be appreciated by those of ordinary skill. Sprayer **122'** is also similar to an ES emitter without an electric field at the tip of the liquid tube: that is, it nebulizes a flowing liquid to create droplets and solvated molecules. In this configuration, solvated analyte molecules and droplets from sprayer **122'** are entrained within gas flowing through sampling inlet **32'**. Again, these solvated analyte molecules and droplets in chamber **30** desolvate due to the counter flow of dry gas and the elevated temperature of heated chamber **30**, and are chemically ionized by reagent ions originating from the corona emitter **124'** within chamber **30**, at pressures less than 1 atm. As such, this configuration provides a sub-atmospheric pressure chemical ionization source. As droplets from sprayer **122'** are not charged, they will not be electrically attracted to sampling inlet **32**. Instead, droplets are directed to aperture **32**, and gas flow through sampling inlet **32'** will entrain such droplets and guide them to the interior of chamber **30**.

Although not shown in FIG. **5**, further analyte ionization may be provided for in chamber **30**—either directly or chemically—such as photo-ionization—could be used within desolvation chamber **30** on its own or in conjunction with an atmospheric ES emitter, or emitters.

Although not shown in the embodiments of FIGS. **1** to **5**, it should be understood that an atmospheric ES emitter, or emitters, could be used in conjunction with a sprayer and

corona emitter in chamber **30**, or sprayers and corona emitters, simultaneously or consecutively.

In another alternate embodiment illustrated in FIG. **6**, a mass analyser interface **20**$^{(v)}$ is depicted. In analyser interface **20**$^{(v)}$ an ES emitter **22"** provides electrospray droplets to an inlet/exit opening **26"** of an interface **35"** along the side wall of chamber **30**. An inlet aperture **33** (as in FIGS. **1** to **5**) in an end wall of chamber **30** may thus be eliminated, and replaced by an inlet aperture **33"** on the side wall of chamber **30"**. A gas jet disruptor flow emanates from gas jet disruptor tube **112** is roughly axially aligned with inlet aperture **110**, creating jet disruption opposing the flow from inlet aperture **110**, as illustrated. Again, a gas source feeds disruptor tube **112**. Of course, additional jet disrupters (not shown), like gas jet disrupter **104** or **108** (FIGS. **3** and **4**), may be included in interface **20**$^{(v)}$.

In another alternate embodiment illustrated in FIG. **7**, a mass analyser interface **20**$^{(vi)}$ that is the same as mass analyser interface **20**$^{(v)}$ in FIG. **6** except that the ES emitter **22"** has been replaced by a sprayer **122"** (like sprayer **122'**—FIG. **5**) to feed solvated molecules and droplets into chamber **30** through aperture **110**. A corona emitter **124"** inside chamber **30**, proximate aperture **110**, completes ionization of the desolvated molecules.

In another alternate embodiment illustrated in FIG. **8**, a mass analyser interface **200** that is similar to mass analyser interface **20** in FIG. **1**. However, sampling inlet **32** and inlet aperture **33** have combined become a single aperture **232**. A gas distribution manifold **270** includes two parallel plates **274***a* and **274***b*. Plate **274***b* defines inlet aperture **232**, and plate **274***b* defines opening **226** to gas manifold **270**. Opening **226** is aligned with inlet aperture **232** to desolvaton chamber **230**. Plates **274***a* and **274***b* are spaced from each other by about 3 mm to define region **278**. An annular passage **276** is formed adjacent the region defined by plates **274***a* and **274***b*. The inlet to annular passage **276** extends from the outer wall defining the annular passage **276**, and is connected with gas supply **238**. Evenly spaced openings on the inner wall of annular passage **276** ensure that gas from supply **238** enters region **278** with a flow toward axis **231**, in a generally axial direction of chamber **230**. A ring ion guide **326** guides ions within chamber **230** to outlet aperture **234**, while a dry gas creating a counter-flow is injected through port **248** from gas supply **250**.

Of course, the above described embodiments are intended to be illustrative only and in no way limiting. The described embodiments of carrying out the invention are susceptible to many modifications of form, arrangement of parts, details and order of operation. The invention, rather, is intended to encompass all such modification within its scope, as defined by the claims.

What is claimed is:

1. A mass analyser interface, comprising:

a desolvation chamber having a generally cylindrical wall, said desolvation chamber maintained at a pressure between 10 Torr and 700 Torr, and having an inlet for receiving neutral solvated analyte particles from a source of analyte particles, and an outlet aperture for feeding ionized particles from said desolvation chamber to downstream stages of a mass analyzer;

an electric field source, for providing an electric field to urge ionized particles within said desolvation chamber from said inlet toward said outlet aperture, and a containment field to contain said ionized particles about a guide axis, creating a downstream flow of said ionized particles along said guide axis to said downstream stages of said mass analyzer;

a gas injection port to inject an upstream gas proximate said outlet aperture, to provide a counter-flow to said downstream flow at said outlet aperture, to slow solvated ionized particles and neutral particles in said downstream flow more than desolvated ionized particles in said downstream flow as said desolvated ionized particles travel toward said outlet aperture;

at least one evacuation port formed downstream of said inlet on said generally cylindrical wall, to allow injected gas to escape from said desolvation chamber, in a direction away from said guide axis;

an annular shroud, encircling said guide axis and in flow communication with said at least one evacuation port, and said annular shroud having an aperture that guides injected gas to flow from said desolvation chamber into said at least one evacuation port generally parallel to said guide axis;

a pump in flow communication with said at least one evacuation port and said aperture, said pump and said at least one evacuation port configured to guide a counter-flow of said injected gas away from said outlet aperture and toward said inlet, and through said annular shroud and through said at least one evacuation port.

2. The mass analyser interface of claim **1**, wherein said source comprises an electrospray emitter, and wherein said solvated analyte particles are said solvated ionized particles.

3. The mass analyser interface of claim **1**, further comprising a corona emitter to ionize analyte particles in said desolvation chamber.

4. The mass analyser interface of claim **1**, further comprising a photo ionizer in said desolvation chamber.

5. The mass analyser interface of claim **1**, further comprising:

a second chamber in flow communication with said desolvation chamber, by way of said outlet aperture connecting said desolvation chamber to said second chamber.

6. The mass analyser interface of claim **1**, further comprising a controller to maintain pressure within said desolvation chamber at less than atmospheric pressure.

7. The mass analyser interface of claim **1**, further comprising a heater for heating said desolvation chamber.

8. The mass analyser interface of claim **7**, wherein said heater heats said desolvation chamber to in excess of 100° C.

9. The mass analyser interface of claim **1**, wherein said outlet aperture is located about a central axis of said desolvation chamber.

10. The mass analyser interface of claim **9**, wherein said downstream flow is along said central axis of said desolvation chamber.

11. The mass analyser interface of claim **10**, wherein said counter-flow is generally opposite to said downstream flow.

12. The mass analyser interface of claim **1**, wherein said desolvation chamber is maintained at a pressure of between about 30 torr to about 250 torr.

13. The mass analyser interface of claim **1**, further comprising an ion guide in said desolvation chamber.

14. The mass analyser interface of claim **13**, wherein said ion guide acts as said electric field source in said desolvation chamber.

15. The mass analyser interface of claim **14**, wherein said ion guide comprises a stacked ring ion guide.

16. The mass analyser interface of claim **14** wherein said ion guide comprises a multi-polar ion guide.

17. A mass analyser comprising the mass analyser interface of claim 1, and a plurality of guide stages, downstream of said desolvation chamber.

18. The mass analyser interface of claim 3, wherein said source volatilizes said analyte particles.

19. The mass analyser interface of claim 1, further comprising a flow disruptor in said desolvation chamber along a path of said downstream flow.

20. The mass analyser interface of claim 19, wherein said flow disruptor comprises at least one jet nozzle.

21. The mass analyser interface of claim 19, wherein said flow disruptor comprises at least one jet nozzle that is not along a central axis of said desolvation chamber.

22. The mass analyser interface of claim 2, further comprising a corona emitter in said desolvation chamber to aid in ionizing analyte in said desolvation chamber.

23. A method of providing desolvated ions in a mass analyser, said method comprising:

providing neutral solvated analyte particles from a source of analyte particles into a desolvation chamber having an inlet and an outlet aperture;

maintaining pressure in said desolvation chamber between 10 Torr and 700 Torr;

providing an electric field to contain ionized particles about a guide axis and urge said ionized particles toward said outlet aperture in a downstream flow;

heating said desolvation chamber to aid in desolvation of solvated ionized particles within said desolvation chamber;

injecting an upstream gas proximate said outlet aperture, to provide a counter-flow to said downstream flow at said outlet aperture, to slow said downstream flow and any neutral particles and any solvated particles entrained therein;

evacuating said upstream gas by way of a pump, through an evacuation port formed downstream of said inlet by way of an annular shroud, encircling said guide axis and in flow communication with said evacuation port;

wherein said annular shroud comprises at least one aperture that guides injected gas to flow from said desolvation chamber in a direction generally parallel to said guide axis and wherein said annular shroud guides said injected gas to evacuate from said evacuation port in a direction generally away from said guide axis;

said evacuation port, said annular shroud and said pump configured to guide the flow of said injected gas in a direction generally parallel to said guide axis away from said outlet aperture and toward said inlet, and through said evacuation port;

providing ionized particles from said desolvation chamber to a downstream stage of said mass analyzer by way of said outlet aperture.

24. The method of claim 23, further comprising ionizing analyte within said desolvation chamber.

25. The method of claim 23, further comprises guiding said ionized particles along said guide axis in said desolvation chamber.

26. The method of claim 23, wherein said analyte particles are provided from a source above atmosphere.

27. The method of claim 23, further comprising ionizing at least some desolvated analyte particles in said desolvation chamber by way of at least one of a corona emitter and a photo ionizer.

28. The method of claim 27, further comprising ionizing at least some of said desolvated analyte particles at an electrospray source.

29. The method of claim 28, wherein said ionizing by way of at least one of a corona emitter and a photo ionizer and said ionizing at least some of said desolvated analyte particles at an electrospray source are performed concurrently.

30. The mass analyser interface of claim 1, wherein the ions in the desolvation chamber arise from within the solvated analyte particles.

31. The mass analyser interface of claim 1, wherein said desolvation chamber is maintained at a pressure less than 76 Torr.

32. The mass analyser interface of claim 1, wherein said counter-flow of said injected gas guides charged solvated particles to reverse direction toward said outlet aperture.

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